Adaptive SOFC for Ultra High Efficiency Power Systems

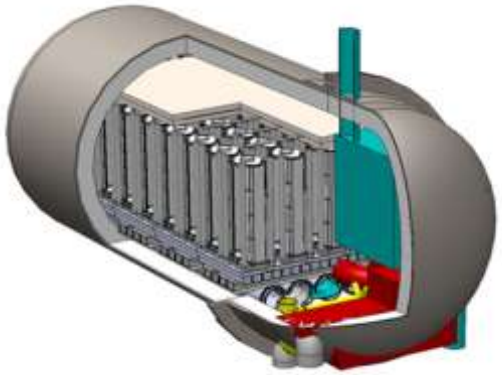
Hossein Ghezel-Ayagh, FuelCell Energy, Inc.

Project Vision

Development of flexible Solid Oxide Fuel Cell (SOFC) technology suitable for integration with other power producing equipment achieving > 70% electrical efficiency based on natural gas lower heating value

7 kW Compact SOFC Architecture (CSA) Stack, Atmospheric Pressure

Project Development



100 kW SOFC Module, Pressurized

Project Overview

Fed. funding:	$3.1M
Length	24 mo.

Team member	Location	Role in project
FuelCell Energy (FCE)	Danbury, CT	Stack Module Design, System Design
Versa Power Systems (VPS)	Calgary, AB	Cell and Stack Design, Fabrication and Testing
University of California, Irvine (UCI)	Irvine, CA	System and Components Dynamics & Control

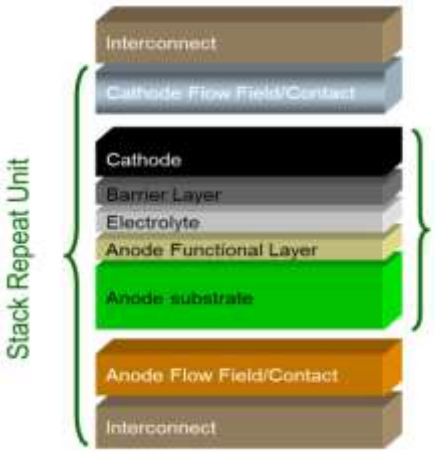
Context/history of project

- FCE and its wholly-owned subsidiary, VPS, have been involved in development of fuel cell systems, including a recent 200kW SOFC unit fueled by natural gas. Both organizations have been collaborating in two ARPA-E projects under REFUEL and REBELS programs
- UCI is a leader in the field of hybrid fuel cell systems and dynamics, including partnerships with Siemens Westinghouse to develop and test the world's first hybrid SOFC-GT system
- FCE and UCI have a long established working relationship, in excess of a decade, including "Advanced Control Modules for Hybrid Fuel Cell/Gas Turbine Power Plants (DE-FG02-02ER86140), and "Validation of an Integrated Hydrogen Energy Station" (DE-FC36-01GO11087)

Innovation and Objectives

Innovation

Develop low-cost Compact SOFC Architecture (CSA) stack technology for pressurized operation, tolerance to cathode Cr species, and adaptability for integrated hybrid system configurations



7-kW CSA Stack

Anode	Ni/YSZ	0.3 - 0.6 mm
Electrolyte	YSZ	5 - 10 μm
Cathode	Conducting ceramic	10 - 50 μm

Task outline, technical objectives

- Develop cell materials and fabrication processes suitable for pressurized operation
- Develop stack technology suitable for operation of up to 4 bar pressure with low degradation in voltage, yielding a stack module cost of $400/kW
- Develop steady-state and dynamic simulation models for design of integrated hybrid system

Tech-to-Market objectives

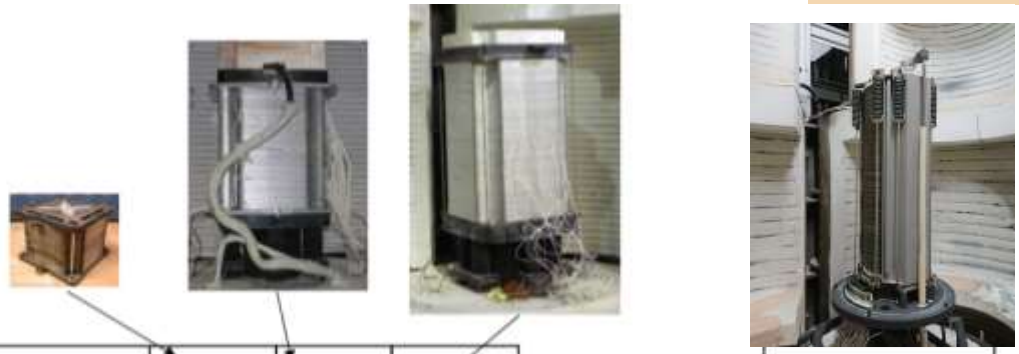
- Utilize FCE's established sales, marketing, and field service infrastructure for fuel cell power plants
- Anticipated first markets are on-site power and microgrids
- Use existing pilot manufacturing facility (500 kW/yr → 5 MW/yr) for market entry

Compact Solid Oxide Architecture (CSA) Stack

1. Thinned components (cell + interconnect) to minimize stack material content (~0.5 kW/kg)
2. Simplified unit cell with fewer components
3. Designed for automated assembly
4. Thermal and flow design to control temperature variations in stack module

Number of Cells	350
Active Area	81 cm^2
Power @ 0.25 W/cm^2	7 kW
Seal Technology	Crystallized glass

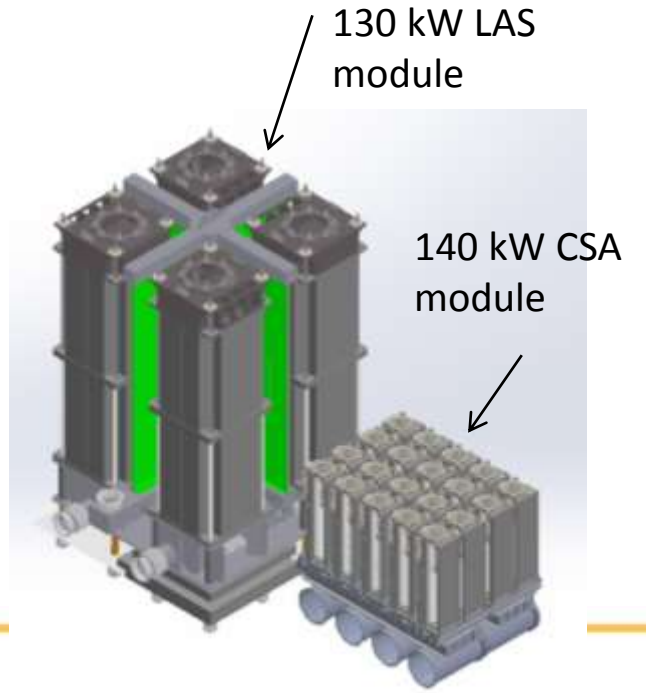
CSA offers low material content stack for commercialization



	Baseline PCI 390 mA/cm²	96 cell Wartsila 360 mA/cm²	120 cell coal based 290 mA/cm²	350 cell CSA Stack At 290 mA/cm²
Gross Power (W)	1100	14900	16200	7000
Stack voltage (Vdc)	24	75	101	295
Weight (kg)	17.3	185	213	15
Power to Weight Ratio (W/kg)	64	80	76	467
Approx. envelope (L)	5.3	69	88	9
Power to Volume Ratio (W/L)	207	215	185	778

6 X

4 X

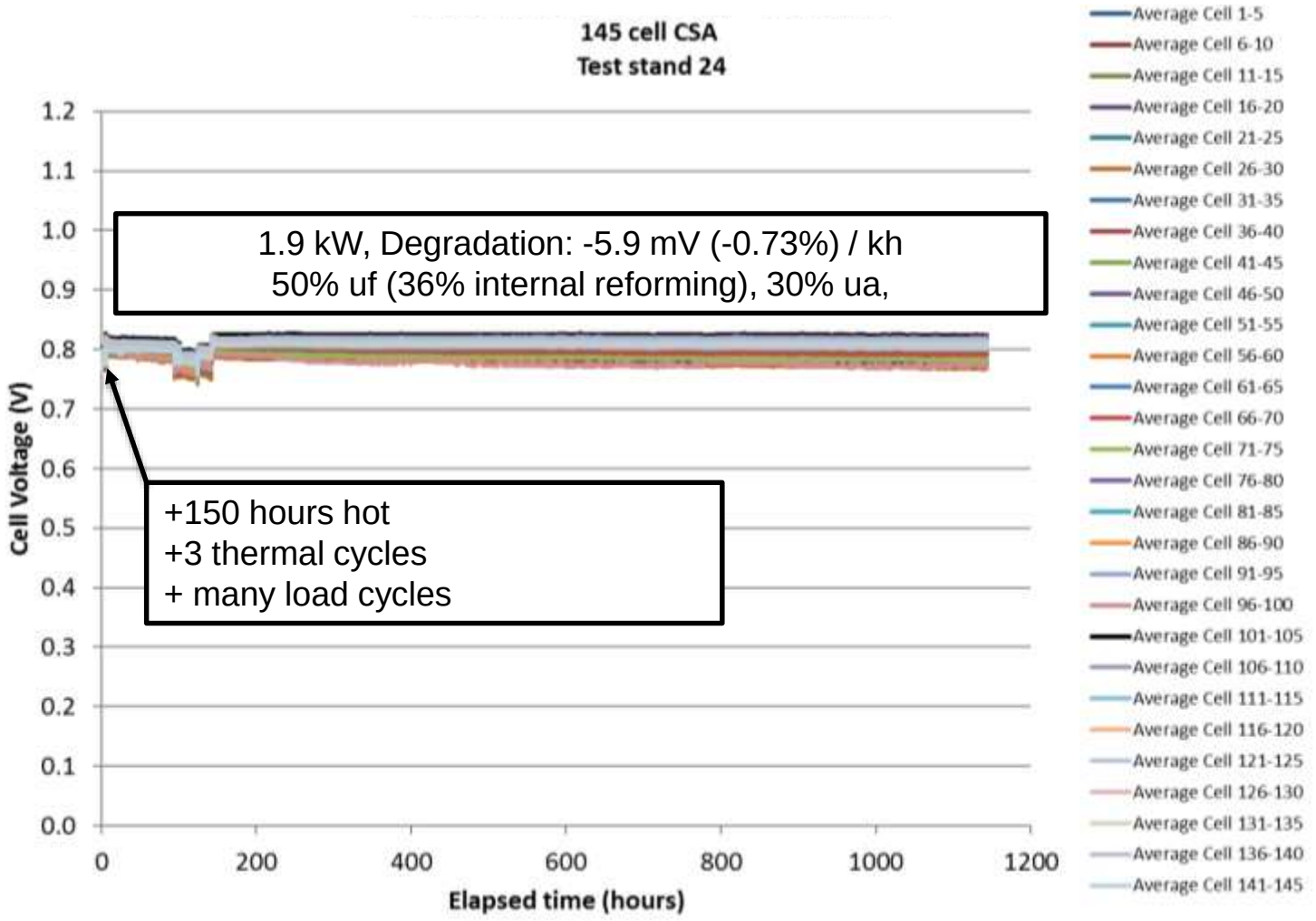


CSA Stack Family

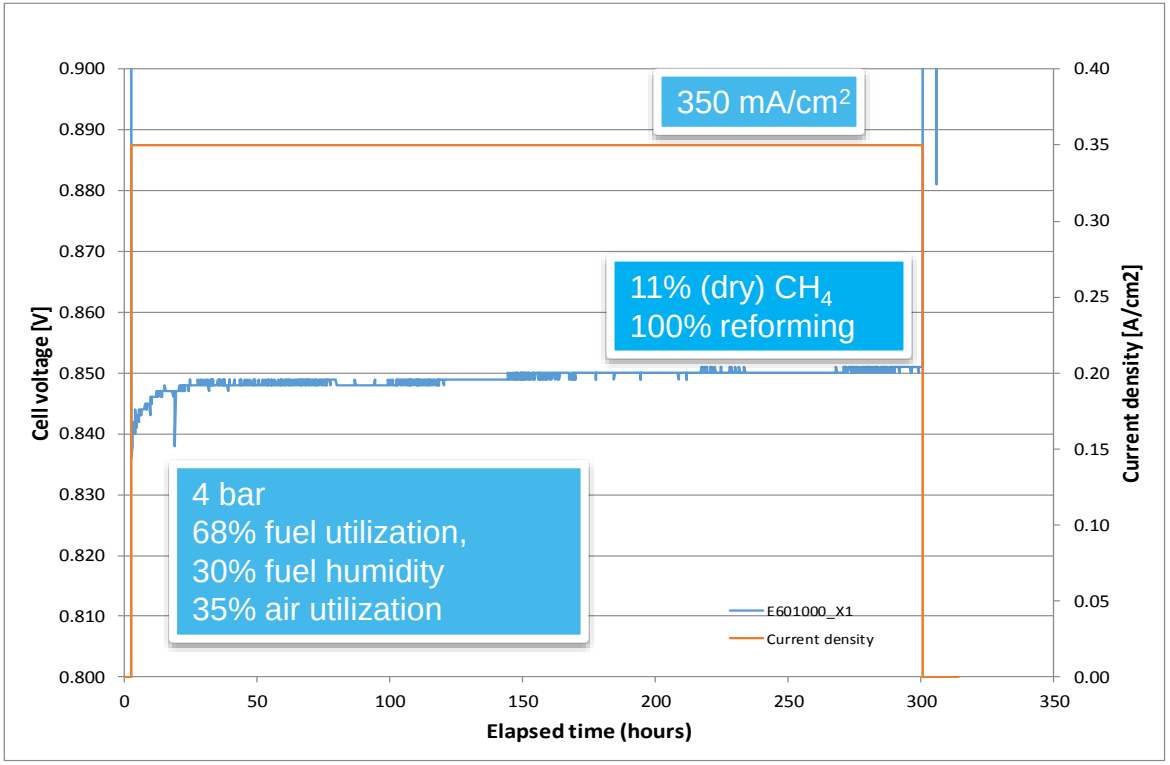
Property	CSA Stack Scale			Comments
	Short	Mid	Full	
Cell count	45	150	350	
Fuel cell voltage, V	38	128	298	At 0.85 V/cell
Stack power, kW	0.9	3.0	7.0	At 0.29 A/cm^2
Stack power, kW	1.24	4.13	9.64	At 0.40 A/cm^2 INTEGRATE - Pressurized
Height, mm	91	211	440	

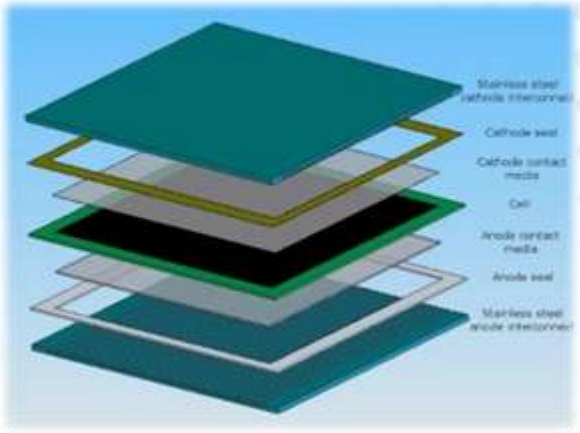
38% stack power up-rate at pressure targeted

145-cell CSA Stack Operational Data



Pressurized Cell Testing





16 cm^2 cell configuration

Pressurized test jig
with glass seals

Met Project Milestone:

Achieved **>850 mV** at **350 mA/cm^2** and **4 bar$_a$** in **16 cm^2** cell and characterize voltage degradation at these conditions over **≥200 hours** and **80% internal reformation** (conversion) of a system relevant anode inlet fuel composition containing **>8% CH4** (dry basis); representing a system configuration with an anode recycle and a pre- reformer upstream of SOFC

Market Applications

Stationary Power Generation

Low cost and ultra high efficiency systems using adaptive SOFC combined with other power cycles provide a superior alternative for distributed electricity generation in near term markets:

- On-site / Micro-grid
- Grid-support

50 kW SOFC System

200 kW SOFC Power Plant

Transportation / Mobile Application

High efficiency, near-zero emissions, fuel storage volume reduction and rapid load following features make hybrid systems candidates for transportation applications

The largest marine fuel cell installation to date is the 330kW MCFC, installed on board Viking Lady (2009-2012)

Risks

Anticipated challenges

- Accelerated performance degradation mainly due to Cr poisoning of cathode due to higher water vapor partial pressure
- Materials degradation and reduced stability at high pressure
- In-stack reforming of natural gas at high pressure
- Pressurized operation driving stricter leak requirements (cell and seals)
- Imparting robustness to tolerate anode-to-cathode differential pressures
- Impact of system dynamics and severe transients/upsets during operation
- Meeting installed cost target of $1800/kW for pressurized systems

Solid Oxide Cell Pilot Manufacturing Process